research review

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APPRAISING FERRIMAGNETIC CRYSTALS: A NEW INSIGHT

Solid State Sciences Laboratory, AFCRL

Solid-state electronics, as every reasonably well-informed person knows, has two primary divisions--semiconductors and magnetics. Semiconductors have preempted the larger share of the spotlight, partly because magnetics have lost their identity in the equipments into which they are incorporated--computers and amplifiers. One kind of magnetic material, ferrimagnetic crystals, holds high potential for improving microwave amplifiers and oscillators. The following story reports on a new insight by AFCRL scientists into magnetic resonance as a property of ferrimagnetic crystal alignment, and new analytical procedures growing out of this insight which greatly simplify application.

If we take a ferrimagnetic crystal such as yttrium iron garnet, place it in an external magnetic field and energize it with microwave energy, chances are that it will exhibit no magnetic resonance at all. But if we carefully align the same crystal so that its lattice structure approximates some ideal relation to the magnetic field, then its resonance will be strong. Let us vary either the intensity of the magnetic field or the crystal temperature, and we see that the resonance is weakened. But we get a strong magnetic resonance again by carefully realigning the crystal to compensate for these changes.

What we are describing here are manifestations of magnetocrystalline anisotropy. It is this which causes the magnetic properties of a ferrimagnetic crystal to vary with crystalline direction. This simply means that it is easier to magnetize the crystal in one direction than in another. To obtain maximum magnetic resonance, the alignment of the crystal with the external magnetic field must be extremely precise. Obtaining this single, preferred alignment is, in fact, the key aspect of crystal analysis.

When the experimenter sets out to determine the anisotropy properties of a ferrimagnetic crystal, he measures the changes in the external magnetic field required to obtain strongest magnetic resonance at different crystal orientations. He attempts to keep the temperature and the energizing

microwave frequency constant. Essentially, this method of analysis has three limitations: the crystalline axes must be aligned with extreme precision, changes in crystal temperature may invalidate results, and the experimental data are difficult to interpret.

Recently, a clearer insight into magnetic resonance in ferrimagnetic crystals has been obtained by Dr. Ernst R. Czerlinsky and Peter D. Gianino of AFCRL. This has resulted in procedures for the utilization of ferrimagnetic materials which do not depend on extremely precise crystal alignment or careful temperature control.

To understand the nature of the discovery, it is necessary to briefly consider magnetic-resonance phenomena. At magnetic resonance, the magnetization vector precesses about an equilibrium. The precession frequency of the magnetic vector is basic to the novel procedures formulated by Czerlinsky and Gianino. The precessional frequency depends on the torques which the magnetic vector experiences both from the external magnetic field and from variations of the anisotropy energy with position in the lattice. Heretofore, all practical application was based on the belief that at only one crystal orientation--one "singular" direction--was the precessional frequency uninfluenced by anisotropy energy and variation with temperature. Ideal crystal orientation was required to guarantee elimination of the temperature effect on magnetic resonance. The studies of Czerlinsky and Gianino led to the evidence that not one, but a continuum of "singular" directions exist. What is meant by "singular" directions in this case are the crystalline orientations at which the precessional motion is not affected by the anisotropy.

Because anisotropy constants are highly temperature-dependent, a slight change in temperature would, under previous procedures, force a reorientation of the crystal to obtain sharpest resonance. But using resonance equations and procedures based on the newly discovered continuum of "singular" directions, temperature becomes a less important consideration.

Experiments have proved the effectiveness of the new measurement approach. In certain planes, deviations up to about 10 degrees from the ideal position of the crystal did not markedly affect the resonance field over a temperature range of approximately 30 degrees Kelvin above and below ambient. ★

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JACOB SEIDEN
Editor

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RESEARCH IN THE THEORETICAL PHYSICS DIVISION OF BATTELLE MEMORIAL INSTITUTE

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The Theoretical Physics Division of Battelle Memorial Institute's Columbus Laboratory was conceived as part of the Laboratory's participation in the basic-research community. This participation, in turn, was motivated by an awareness of the importance of basic research to contemporary applied research. Because of the Laboratory's large involvement with materials research, the over-all basic-research program emphasizes solid-state studies. This is particularly true of the work in theoretical physics.

The Theoretical Physics Division, headed by Dr. F. J. Milford, now consists of eight senior staff members who are working in five main areas: electronic structure of solids; dislocations; magnetism; radiation damage; and the theory of surfaces. This group is partially supported by the Solid State Sciences Division of AFOSR. Their work is discussed in the following paragraphs.

Electronic Structure of Solids. The electronic structure of solids or, more precisely, a knowledge of the electronic wave functions in solids, is crucial to an understanding of their physical properties. Particularly in the case of metals, with which this work has been primarily concerned, the electronic wave functions must be known in order to understand cohesive energy, electrical conductivity, magnetic susceptibility and many other interesting practical properties.

Many models have been proposed and, from them, wave functions determined. It has not, however, often been possible to test these wave functions directly; but rather, it has been necessary to use them in elaborate calculations of various physical properties, and then try to estimate the quality of the wave function on the basis of the agreement (or lack thereof) of these calculated properties with experiment.

Recently, some more direct tests have become available; in particular, the Knight shift measures the square of the wave function at a nuclear site averaged over the Fermi surface. Although even this leaves much to be desired, it represents a considerably more direct test of wave functions than do most other phenomena. For this reason, our studies of the electronic structure of solids have concentrated on the Knight shift and closely allied topics. The two main aspects of the work have been actual calculations of the Knight shift based on various models, and refinement of the general theory of the Knight shift through the inclusion of diamagnetic effects and more rigorous statistical mechanical approaches.

One of the areas which has been extensively investigated in the course of this work is magnetic shielding and susceptibility. Studies in this area provide useful information about Fermi surfaces and wave functions in solids; these are in many ways less complex to study theoretically than are transport properties. The information about electronic structure obtained from the correlation of theory and experiment is useful in developing methods of synthesizing alloys, intermetallics, or semiconductors of desired physical properties. Many aspects of the structure and behavior of elemental metals, semiconductors, and relatively simple compounds are at present incompletely understood; these investigations are expected to provide useful information concerning the electronic structure of such substances and, perhaps, of new classes of materials also.

The past year has been devoted mostly to studying the effects of alloying on the magnetic susceptibility (and the closely related problem of the specific heat) in simple

metals, and to investigating the oscillatory terms in the susceptibility. Results in good agreement with experiment are obtained for the specific heats of noble-metal alloys by using a simple virtual crystal approximation; a priori justification for the use of this approximation is being investigated. The oscillatory susceptibility has been investigated in a simple model which none the less shows neck orbits, magnetic breakdown, and other topical phenomena of the deHaas-van Alphen effect, and which also predicts some new periods which, if they persist in a more realistic model, should be looked for experimentally. A simple extension to polyvalent metals was made of the theory previously given for the susceptibility of monovalent metals, and numerical results for some polyvalent typical metals obtained. The results are not as satisfying as for the monovalent metals, and the reasons for the discrepancies are being investigated. Preliminary investigations of inclusion of relativistic and superconducting effects were carried out.

The Theory of Dislocations. It is now generally accepted that dislocations are primarily responsible for the difference between the mechanical properties of single crystals and those of metals in their normal metallurgical state. In consequence, it is desirable to understand dislocations as completely as possible. There are many ways in which this understanding can be approached; and the differences among them often represent differences in disciplinary philosophy. In particular, metallurgists tend to consider the effects on mechanical properties of the relatively large number of dislocations that are found in even relatively perfect crystals, while physicists tend to consider the behavior of single dislocations. It seems reasonable to speculate that, when these two approaches connect, there may be some enormous progress. The approach taken in the Theoretical Physics Division has been to study forces on single dislocations, in particular, the so-called Peierls stress. The principal results have been the construction of self-consistent models and the concomitant nonlinear differential-difference equations. These equations have been solved for a wide range of possible situations, and some proposals for experimental verification have been made.

Magnetism. Although, in some ways, the magnetic properties of solids have been exploited to a lesser extent than have some others, it is none the less apparent that, recently, highly sophisticated magnetic devices have begun to play an important role in technological development. From the enormous range of possible areas of research in magnetism, two topics of particular interest to members of the Theoretical Physics Division have been selected, viz., the theory of spin waves and the theory of properties of small exchange coupled clusters. The work on spin waves has been concerned mainly with magnetite, which might well be called the original ferrite. Calculations of the heat capacity, saturation magnetization and spin wave dispersion curves have been made, and the results compared with experiments. The most recent work has been concerned with renormalization of spin wave energies, and represents the true frontier of research in this area. The work on exchange interactions of small clusters has been an attempt to extract exchange integrals from experimental susceptibility data. The main contribution is, of course, an enhanced understanding of these exchange interactions. The work has been done in collaboration with Professor J. G. Daunt of Ohio State University.

Radiation Damage. The objective of this research is to improve the understanding of radiation damage in solids, sputtering, and similar phenomena. Progress on these problems has been severely limited in the past by the inadequacy of information on the ranges of ions in the velocity range where elastic collisions are more important for energy loss than are electronic processes. In the last half dozen years, the situation has been improving rapidly, through data obtained with much improved techniques in five or six laboratories, and through related theoretical contributions from a number of places. Early work at Battelle involved cal-

culations of scattering cross sections for potentials approximating the repulsion between colliding atoms; but, for some time, emphasis has been on using the Boltzmann transport equation to determine the over-all effect of a sequence of collisions.

Theoretical Studies of Surface Phenomena. The burgeoning importance of sophisticated theories of surfaces to such areas as heterogeneous catalysis, high-speed aerodynamics, and others, has led to the involvement of the Theoretical Physics Division in this, its newest, area of research. Work has been started on the theory of the interaction of gas molecules with surfaces, which is of crucial importance to vapor deposition, high-speed aerodynamics, and several other areas. An initial effort to understand the scattering process directly and rapidly became intractable and caused a return to the accommodation coefficient treatment. Some new calculations are in progress, and it is hoped that during 1965 substantial advance will be made. In addition, a review of the current status of surface science has been prepared, mainly to insure that the work being undertaken has real significance. ★

DIGITAL FILTERING

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Historically, methods for processing signals that are functions of continuous time were developed long before the advent of high-speed digital computers. When high-speed computing facilities did become available, the communications and control engineers were not the people who developed computing techniques. As a result, the filtering theory that had been highly developed for continuous-time signals was not applied in full force for the processing of digital signals.

This problem of tying together the theories of filtering digital signals and continuous (analog) signals was solved recently by Dr. Kenneth A. Steiglitz while at New York University. (Dr. Steiglitz is now assistant professor of electrical engineering at Princeton University.) The problem is part of the research in sampled data theory and digital filters supported by the Applied Mathematics Division, Directorate of Mathematical Sciences, AFOSR, at New York University under the direction of Dean John Ragazzini and Professor Sheldon Chang. (Professor Chang is now at the State University of New York, Stony Brook.)

The results of this research appear in the technical report, AFOSR 64-1664. The primary results include the construction of a specific relationship (isomorphism) which connects the filtering theories for continuous-time and discrete-time signals. In the linear time-invariant case, the two theories are shown to be essentially identical. This means that many optimization problems can be solved simultaneously for continuous-time and digital systems. The problem of estimating the power-spectral density of a signal from equally spaced samples is also included.

One part of the technical report uses the isomorphism developed to reduce the approximation problem for digital filters to that for continuous-time filters. This allows the designer of digital-filtering computer programs to use many of the concepts which have proven important to the communications engineers.

This research has already been found to be of direct value to the Air Force. The results obtained by the Rome Air Development Center (RTD/AFSC) in analyzing experimental data for the Echo II satellite have been improved by the application of the theories discussed in the technical report. ★

REFERENCE:

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CAT (Clear Air Turbulence): FINDING A SUITABLE BELL

Aerospace Instrumentation Laboratory, AFCRL

At jet speeds, an airplane hits severe Clear Air Turbulence (CAT) like a brick wall. It is a frightening and sometimes dangerous experience. Several military and civilian aircraft crashes have been attributed to CAT. Severest pockets are generally found at altitudes greater than 20,000 feet, and often near the tropospheric jet stream at around 30,000 feet. AFCRL has Air Force responsibility for developing CAT detection equipment, and for research on CAT forecasting techniques. Some of the detectors and detection techniques being studied at AFCRL are infrared and microwave radiometry, radar, electric-field changes, ozone-concentration changes and laser-beam scattering. One detection technique that has been advanced with some vigor is the change-in-temperature technique. AFCRL has made a thorough study of the technique with negative conclusions. This study is the subject of the following story.

Recently proposed and publicized as a method for detecting clear air turbulence is a technique based on horizontal changes in the air temperature. It has been suggested that, if the temperature changes 3.5 degrees C or more in five minutes of horizontal jet flight, this will serve as an advance indicator of CAT.

George McLean of AFCRL has made a thoroughgoing study of this proposal, and has found that the method doesn't work often enough to be really useful. McLean approached the CAT problem from two directions, one statistical, the other theoretical. Using temperature and turbulence data collected during the Air Force's Project Jet Stream research flights in 1957-1958, he found that the temperature-change method of CAT detection would have scored a low percentage of successes on these flights. Then, using a conceptual model of the jet stream which he had derived from Project Jet Stream data in an earlier study, he showed why this method was unreliable.

It is known that a larger percentage of severe clear air turbulence occurs near the jet stream than anywhere else. McLean found that CAT near the jet stream is indeed associated with a sharp horizontal change in temperature. This change does, in fact, define what is known as a "jet front." The jet stream's "core"--the region of highest wind speed--is at the top of the jet front, and the two boundaries of this front slope downward from the core as far as 10,000 feet.

If an airplane flies through the jet front at right angles to the core, it will cross both boundaries of the front and encounter a sharp horizontal change in temperature. Regions of clear air turbulence which occur near the jet stream usually occur along one or the other of the jet front's boundaries. Thus, an airplane flying through a jet front in one direction might have detected a temperature change of 3.5 degrees C about two minutes before it hit a pocket of turbulence; but if it had been flying in the opposite direction, it would have hit the turbulence first and encountered the temperature change afterwards.

If CAT occurred only near jet streams, the temperature-change method would miss detecting CAT at least 50 per cent of the time. However, its actual percentage of failures is much higher because a good deal of CAT doesn't occur near jet streams, and is not associated with any temperature change at all. In addition, if an aircraft were flying through a jet front at an altitude either above or below that of the CAT, it would encounter a sharp temperature change without hitting any CAT at all. This would happen more than 80 per cent of the time, according to McLean. The rate of "false alarms" given by the temperature-change method would therefore be prohibitively high. ★

DETONATION CHARACTERISTICS OF LOW-DENSITY GRANULAR MATERIALS

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The detonability and the detonation-sensitivity of materials used as explosives, propellants, or propellant components are of widespread technological interest, particularly in the space program. Typical applications--explosive bolts, cutting charges, detonators, and igniters--require shock waves of high strength (hundreds of kilobars), and controlled intensity and duration. Reaction waves moving at high, constant, and controllable velocities (between 2 and 8 mm/microsecond) are used in delay lines to insure accurate timing of events.

One of the current urgent technological problems in the space program concerns initiators and detonators for precision sequencing and initiation of events at various stages of a mission; the event must occur on demand, and with close time and pressure tolerances. Frequently, there are hundreds of such devices in one vehicle. Each device must be safe and reliable, and it ought to be inexpensive. Any improvement in safety or reliability has a marked effect on the efficiency and economy of a space mission. Inclusion in initiators of primary explosives (e.g., lead azide), or metal-oxidant mixes (zirconium perchlorates) has brought with it spark and mechanical sensitivity problems, as well as susceptibility to initiation by strong electromagnetic radiation. Efforts to increase safety in these respects are frequently ineffective; almost inevitably they complicate the over-all system, and may result in decreased reliability. It is felt that simultaneous improvement in safety and reliability can be accomplished only by finding ways to make use of the detonation properties of less sensitive secondary explosives.

The phenomenon of detonation also involves the susceptibility of propellant materials to unanticipated and undesired detonation. Propellants and propellant components are high-energy chemicals and, as chemists succeed in improving performance by increasing energy, propellants become indistinguishable from explosives. Being explosives, they detonate if mishandled, with resultant loss of life, loss of property, abortion of mission. Today, speed is vital, redundancy of safety devices is undesirable because of weight limits, and proximity of personnel to propellant or explosive is unavoidable both on ground and in a manned vehicle. Environmental hazards must be controlled with precision, in order simultaneously to avoid accidents, and to avoid hampering a mission with unnecessary safety requirements. However, our present knowledge of the mechanisms of detonation is inadequate to accomplish this precise control, and research is necessary to achieve it.

It is known that detonation can be initiated in a number of ways--e.g., shock, spark, or heat. It is also known that the physical form of the material--e.g., solid (homogeneous or granular), liquid, or gaseous--affects the behavior. By way of example, considerable evidence exists that homogeneous liquids such as liquid TNT, nitromethane, and other more exotic space-age liquid propellants are shock-initiated by the mechanism of shock-heating a volume of the liquid to the thermal ignition temperature. The high-velocity, steady, so-called Chapman-Jouguet detonation wave is believed to propagate by a similar mechanism. (1) On the other hand, the mechanisms of shock-initiation and detonation-wave propagation in granular explosives are matters on which the evidence is much slimmer, and there is considerable disagreement. Two examples of such granular materials are PETN, a secondary explosive which offers promise as a major component of a detonator safer and more reliable than the present electroexplosive devices, and ammonium perchlorate, an oxidizer widely used in composite propellants.

Proposed mechanisms of shock initiation in such granular materials as PETN and ammonium perchlorate include heating by

stagnation of shock-accelerated material, friction between adjoining moving grains, compression of the gas in the interspaces, shock compression of the gas in the interspaces, and shock compression and heating within the grains. Proposed mechanisms of the wave propagation which follows initiation include grain-surface burning and detonation directly through the homogeneous interior of the individual grains.

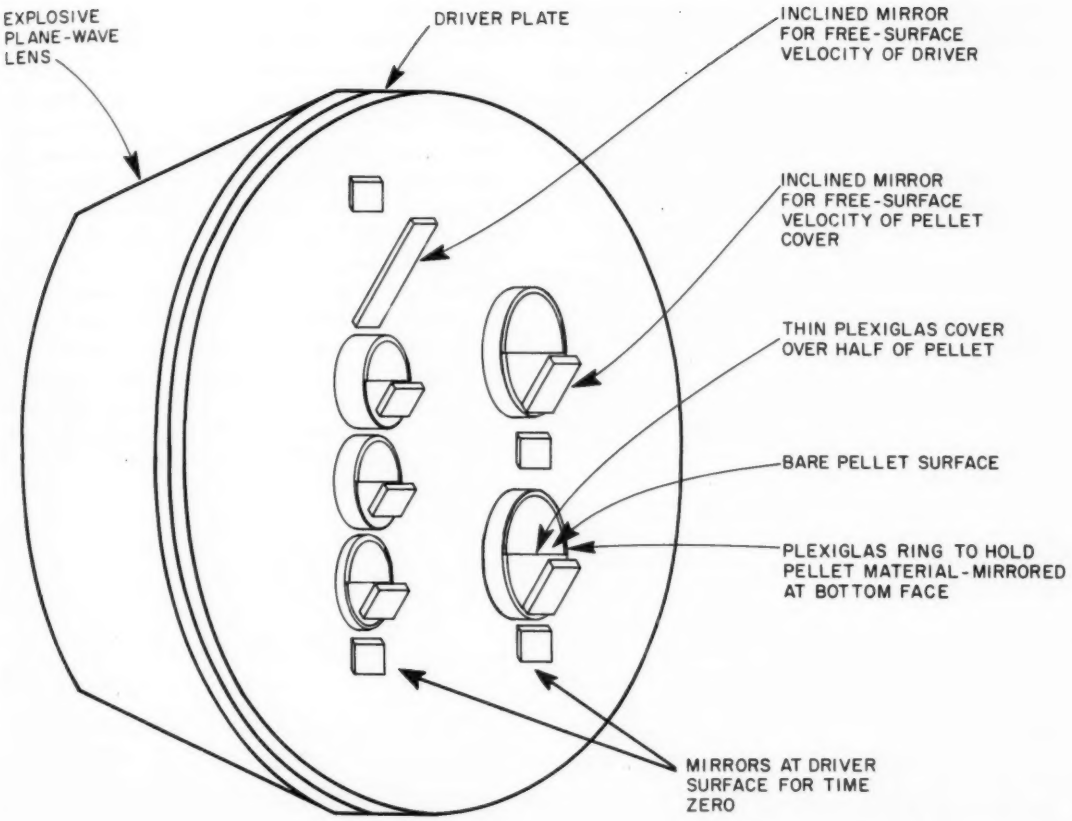
Faced with a variety of alternative mechanisms and theories, the best course of action is to observe in several very different explosives the actual behavior with the most sensitive techniques available, and then to reconcile observations with theory. Shock-wave experimental techniques used on nonreactive materials have advanced to a high degree of precision and effectiveness in the last decade. To apply these techniques to materials which react chemically during the event complicates both experiment and analysis. Nevertheless, modern high-speed optical and electronic tools permit attempts to detect and measure precisely the sequence of events when a shock enters a chemically reactive material. Possible observations include pressure, wave velocity, and material velocity as a function of time and position within the shock.

The events which occur during shock initiation of granular ammonium perchlorate at a loading density of 1 g/cm^3 are currently being studied in a program directed by Drs. Marjorie W. Evans and L. B. Seely of Stanford Research Institute, Menlo Park, Calif., sponsored by AFOSR under Contract AF 49(638)-1124. Ammonium perchlorate provides an interesting and useful contrast to PETN in detonative behavior. Detonation can be shock-initiated in PETN at 1 g/cm^3 by a 2-kbar shock; (2) ammonium perchlorate requires 18 kbar. PETN is a powerful secondary explosive; ammonium perchlorate is not usually classed as an explosive.

The experiments consist of studying the compression of ammonium perchlorate in the shock-pressure range, 2 to 100 kbar. This range includes regions in which no reaction will occur in a reasonable reaction time, those in which initiation occurs with build-up to steady-state within the experimental observation time, and those in which overdriven initiation occurs followed eventually by build-down to steady-state. A precise explosive plane-wave lens is used to drive the shock into an array of test pellets of various thicknesses, which are situated on a driver plate. The observational tool is a moving-image slit camera. The measurements include: a) arrival time of shock at bottom of test pellets; b) planarity of wave; c) free-surface velocity of the attenuator; d) transit time of wave through test pellets; and e) pressure in the wave emerging from the pellet. In this technique, many thicknesses of ammonium perchlorate can be exposed to the same shock to determine the depth at which the nonreactive shock becomes a reactive wave.

A typical experimental arrangement is shown in Figure 1, and the resulting moving-image picture in Figure 2. In this case, five ammonium perchlorate pellets of various lengths were arranged on a brass driver plate so that each was subject to the same shock, and the shocks recorded on two overwriting camera slits. For each film, the time of arrival of the shock at the bottom of the pellets is a prerequisite to extraction of more complicated data. In Figure 2, signals caused by arrival of the shock at the surface of the driver plate are indicated by the lines marked A and A' for the two slits, respectively. From these signals an indication of planarity is easily obtained. Where there is some variation between pellets, the individual signals can be used for their respective pellets. Another basic piece of information, the pressure of the shock in the brass attenuator plate is measured by the angle of the trace marked B in Figure 2. Determination of the pressure independently for each shot minimizes the shot-to-shot variance. From this can be calculated the pressure in the ammonium perchlorate when the shock first enters.

Perhaps the most important data to be obtained from the films are the times of arrival of the shocks at the top surface of the ammonium-perchlorate pellets. For this purpose, half of each top surface is left exposed to scatter light incident from an argon flash bomb. A drop in the intensity of


EXPLOSIVE PLANE-WAVE LENS
DRIVER PLATE
INCLINED MIRROR FOR FREE-SURFACE VELOCITY OF DRIVER
INCLINED MIRROR FOR FREE-SURFACE VELOCITY OF PELLET COVER
THIN PLEXIGLAS COVER OVER HALF OF PELLET
BARE PELLET SURFACE
PLEXIGLAS RING TO HOLD PELLET MATERIAL - MIRRORED AT BOTTOM FACE
MIRRORS AT DRIVER SURFACE FOR TIME ZERO

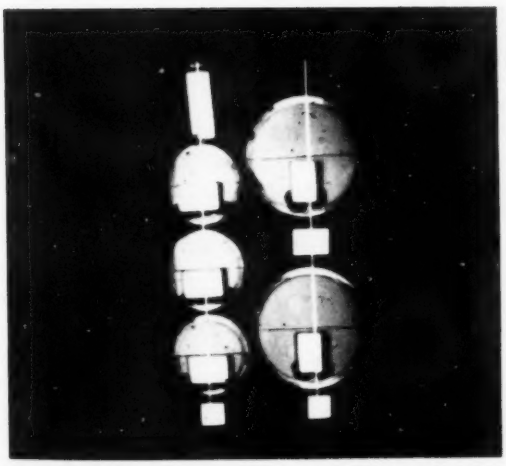


Fig 1. TYPICAL EXPERIMENTAL ARRANGEMENT USED IN STUDYING INITIATION OF DETONATION IN AMMONIUM PERCHLORATE

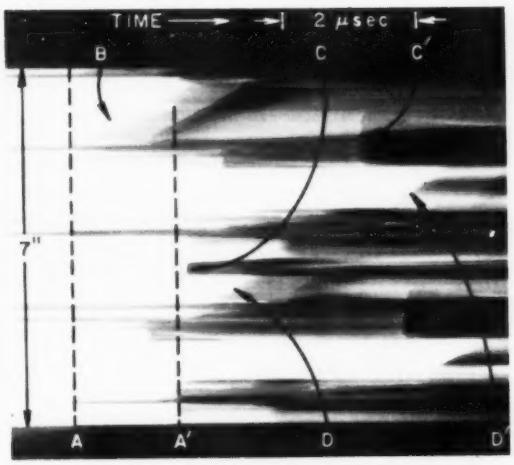


Fig.2. MOVING– IMAGE PICTURE OBTAINED USING THE EXPERIMENTAL ARRANGEMENT OF Fig. 1

scattered light indicates the arrival of the shock. Two such signals, one on each slit, are marked C and C' in Figure 2. The data plotted as distance against time show the acceleration of the wave as chemical reaction becomes effective, and indicate for long pellets a velocity characteristic of the full-strength detonation wave.

On the other half of the pellets, a detection system indicates the pressure developed within the ammonium perchlorate. Each half pellet is covered with a 1-1/2-mm sheet of Plexiglass. The pressure in the Plexiglass is measured by the angled-mirror technique yielding signals such as marked D and D' in Figure 2. Calculations can then be made to give the pressure at the top of the ammonium-perchlorate pellets. In short pellets, where no build-up has occurred, the pressure measured at the end is essentially the same as that of the entering shock. For somewhat longer pellets, the pressure is higher, indicating that the wave is being augmented by the chemical reaction. For the longest pellets, the pressures approach those characteristic of a full-strength detonation. Especially interesting information is being uncovered for overdriven initiation, for which rather high pressures have been measured. Data on developing detonations were first reported by Fauquinon (3) who used the shock velocity in Lucite to indicate the pressure. The present technique has certain practical advantages, and is capable of extending the measurements to many unusual conditions.

When the technique becomes routine, it will be possible to observe the effect of grain size, loading density, interstitial gas composition and pressure, and chemical catalysts. Closely documented behavior over this set of parameters should yield insight into the mechanisms of shock-initiation, build-up to steady detonation, and steady detonation. ★

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STABLE ORGANOSILICON SUBSTANCES

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Over a hundred years ago (1863), Friedel and Crafts reported the synthesis of the first organosilicon compound, tetraethylsilane. By the turn of the century, a few additional compounds had been made, primarily to use as comparisons with analogous carbon compounds. Research during the early years of the twentieth century led to polymers with Si-O-Si backbones, which were called silicones. (Kipping at Nottingham, England, named these polymeric substances "silicones," expecting silicon analogs of ketones as reaction products.) These compounds are the prototypes of today's commercially important polysiloxane fluids, rubbers, and resins.

During the past 25 years, a great deal of research effort has gone into synthesizing new compounds and understanding the chemistry of the many organic derivatives of silicon. Recently, with support from the Directorate of Chemical Sciences, AFOSR, Dr. Robert West at the University of Wisconsin has made noteworthy basic contributions to this important area of chemistry. Among these was the synthesis and characterization of the remarkably stable azidotriphenylsilane, $(C_6H_5)_3SiN_3$. Although azide compounds are generally sensitive to heat and shock, this azide derivative underwent only partial decomposition when heated to over 200°C. Dr. West attributes this stability to dative pi bonding between the nitrogen and silicon atoms, made possible by contributions of the d orbital electrons in silicon. He has found that azidosilanes (as well as azido-

methanes and azidogermanes) can act as Lewis bases (electron pair donors), forming 1:1 complexes with Lewis acids (electron pair acceptors) BBr_3, $SnCl_4$ and $SbCl_5$. There are two possible sites on the azide group where electron donation to a Lewis acid might occur: the nitrogen bonded to the organometallic group, or the terminal nitrogen. Infrared data are compatible with the structure shown for the azidotrimethylsilane-boron tribromide adduct in Figure 1, where the Lewis acid is bonded to the alpha nitrogen.

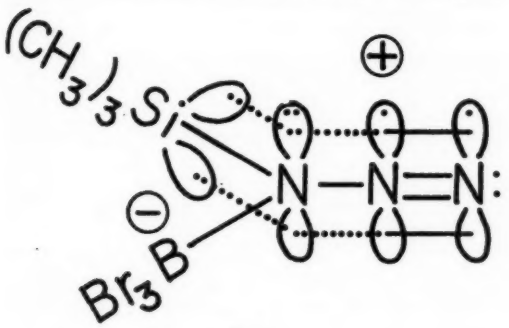
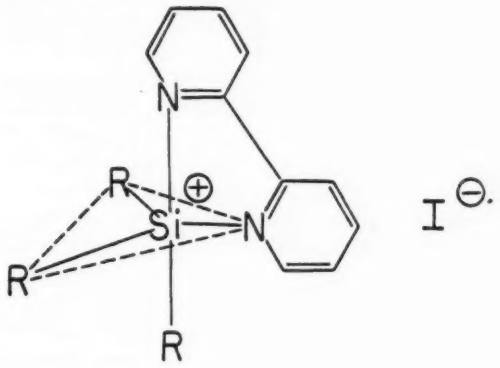


Fig. 1

The complexes of silyl azides with boron tribromide or tin tetrachloride are remarkably stable, whereas the antimony pentachloride adducts were found to be quite unstable.

In still another aspect of organosilicon research, Dr. West and coworkers prepared the compounds triphenyl (bipyridyl) silicon iodide and bromide, which dissociate in dichloromethane solvent to yield the stable positively charged siliconium ion $(C_6H_5)_3$ Si(bipyridyl)+ (Figure 2).



where R = C_6H_5

Fig. 2

These siliconium ions, which are analogous to the carbonium ions in organic chemistry, represent the first known pentaco-ordinate species for silicon bonded to three organic groups. The research opens up new approaches to the synthesis of materials for various Air Force applications supplementing the now versatile and extremely useful four-bonded silicon compounds. ★

LASER BEAM BOUNCED FROM SATELLITE

Terrestrial Sciences Laboratory, AFCRL

Two AFCRL scientists have hit a satellite with light from a laser and, for the first time, photographed its reflection. This feat represents a significant step forward in the refinement of satellite geodesy techniques. Such techniques enable scientists to determine with great precision the distances between two or more widely separated points on the earth's surface.

The short, intense pulse of light was fired from a ruby laser, reflected from NASA's Explorer 22 satellite, and photographed on 21 January 1965. Robert Iliff and Theodore Wirtanen of AFCRL conducted the experiment. Both the laser and the photographic equipment which were used are located atop an AFCRL building at L. G. Hanscom Field, Bedford, Mass.

To use the technique for geodetic measurements, two or more ground sites are needed. By photographing the reflected laser light against a background of stars, it is possible, by triangulation, to compute with great precision the distance between the two sites. In operation, a geodetic satellite network would be established consisting of two permanent stations whose longitude and latitude are precisely known, and a series of

field sites at points on the earth whose locations are not known very accurately. All stations would fire their lasers at the satellite simultaneously, and photograph the reflections against a background of stars. In this way, each station can determine the satellite's position relative to its own with an accuracy not possible by any other means.

The acronym for this technique is LARGOS (for Laser Activated Reflecting Geodetic Optical Satellite), and the basic idea was conceived at AFCRL. NASA's Explorer 22 satellite, which carries the reflectors required for LARGOS, was launched into a nearly circular orbit 600 miles high on 9 October 1964. The satellite is automatically stabilized so that its array of 360 quartz reflectors points downward as it passes over the northern hemisphere. Each reflector is designed so that it reflects a beam of light back along the same path it came.

LARGOS represents a more efficienct use of satellites for geodetic research than its successful predecessor, ANNA. ANNA, which is still in operation, carries a flashing-light system developed at AFCRL. Each flash can be photographed against a star background to find the satellite's position from which geodetic measurements can then be made. The LARGOS concept will provide a geodetic capability for a much longer time and less expensively, since it doesn't require a larger power supply or other complex equipment to be carried aboard the satellite.

Since the launch of Explorer 22, several other research groups, as well as AFCRL, have attempted to reflect a beam of laser light from the satellite. Although there was limited success in recording the reflected laser beam with photoelectric cells, none were able to photograph the reflection. It is important to photograph the reflected laser beam because a photograph also includes a background of stars from which the satellite's angle of elevation can be exactly determined.

When they photographed the reflected laser beam, AFCRL scientists Iliff and Wirtanen also set a distance record for both photographic and photoelectric detection of a reflected laser signal. The slant range to the satellite was about 950 miles. ★

SHRINKING MOON?

Space Physics Laboratory, AFCRL

The moon may be losing weight. Recent hypervelocity impacts on a variety of target materials have shown that, for every ton of meteoroidal material swept up by the moon, up to four tons of lunar-surface material could be blasted back into space from the impacts.

Estimation of the rate of meteoroidal impact on the moon has been made by Captain Vern G. Smalley of AFCRL. By exploring the relationship of the earth and the moon to the velocities of the meteoroids, Smalley found that it was possible to determine the ratio of meteoroidal fluxes striking the earth to those striking the moon when certain reasonable assumptions were made.

Determining the ratio of material striking the earth to that striking the moon necessitated knowledge of the mass-velocity-frequency spectra of meteoroidal debris in space. To date, these data have been totally nonexistent. Satellites which can measure the near-earth flux of material cannot differentiate between meteoroids coming from interplanetary space and those coming from the dust cloud which is supposed to surround the earth. Satellites are further hindered by not being able to accurately differentiate between the effects of meteoroidal mass and velocity on the recording apparatus. Ground-based observations of meteors using photographic or radar techniques have suffered equally. The ground-based observations are able to determine the velocities, but must grossly approximate the masses of the meteoroids. As a result of these limitations, no data exists which is both complete and accurate.

It is possible to approximate the mass-velocity-frequency data by assuming that, within a mass range, the frequencies and velocities of the meteoroids are related by a Gaussian distribution. Then, by assuming that the earth and the moon are sufficiently separated so that the presence of one does not influence the quantity of material striking the other, the ratio of fluxes can be found. Making these assumptions, it was found that

there are approximately four times as many impacts on earth per square meter as there are on the moon per square meter for an average meteoroidal velocity of 15 km/sec. Other ratios were found for other velocities.

The results of impacts on the earth obviously differ from impacts on the moon, for reasons of atmosphere and gravity. Because there is no atmosphere on the moon, there is no drag on the lunar material which is blasted from impact craters. If the velocity of the ejected debris is greater than the lunar escape velocity (2.38 km/sec), the debris will escape from the moon. Considering the differences in effects of impact, the earth may be gaining weight at the rate of about 10,000 tons per day by the collection of meteoroids, while the moon is possibly losing weight at the rate of 600 tons per day. Even at this seemingly large rate, it would take 4×10^{13} (or forty-thousand billion) years for the moon to lose 1/10th its present mass. The moon's present age is estimated to be only 4.5 billion years. ★

impact-pressure behavior in rarefied hypersonic flow

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The birth of the space age with its attendant high-altitude flight problems has stimulated interest in rarefied gas dynamics. As a result, study efforts in low-density aerodynamics have been steadily increasing. Although theoretical work has progressed rapidly, experimental verification of theoretical results has lagged because of difficulties in simulating low-density, high Mach number air flows in the laboratory. As an example, one major problem encountered in experimental simulation of low-density air flows is caused by the excessively thick boundary layers which occur at these conditions. When this happens in a wind-tunnel nozzle, the test section may become filled with boundary layer and the useable test core may be very small. In the past, the study of low-density aerodynamics, especially in the continuous-type wind tunnel, has generally been limited to: (1) slightly rarefied flows at supersonic to low-hypersonic Mach numbers; or (2) very rarefied flows at very low Mach numbers. Therefore, the intermediate low-density flow regimes are still relatively unexplored.

One of the problems related to low-density gas flows is that of determining the behavior of the impact pressure on the nose of a blunt body with increasing rarefaction, and establishing the controlling parameters which govern this behavior. An in-house study of this subject has just been completed and reported (Ref. 1). Additional study objectives were to explore the behavior of the impact pressure in terms of the prevailing flow phenomena, and to further examine the available theory with regard to its limitations.

It has been qualitatively established that, as the flow becomes slightly rarefied, the impact pressure decreases to roughly 95 per cent of the continuum flow value; with further rarefaction, the pressure then increases until the free molecule pressure, which may be several times greater than the continuum impact pressure, is asymptotically approached. In this pressure study, it was possible to obtain only moderately rarefied flow, although elevated hypersonic Mach numbers were achieved. To attain the desired test conditions, a small hypersonic tunnel was modified by extending the length of an existing conical nozzle having a relatively large expansion angle. Also, a single-stage air ejector system was installed between the test section and the vacuum source which gave the required pressure ratio while operating with low stagnation reservoir pressures. Although the resulting test core in the test section was small, it was determined to be sufficiently large to accommodate models up to 0.25 inch in diameter. Four sets of

blunt impact-pressure probes served as the test bodies; each set had a different tip configuration. A set consisted of either 5 or 7 probes, which were graduated in size. During the test, the Mach number and the pertinent stream conditions were held constant, and only the probe size changed in order to change the Knudsen number and the probe Reynolds number. Three test Mach numbers of 14.2, 16.7, and 18.3 were used.

In general, small low-density tunnels cannot operate at high enough pressures to produce continuum flow. Therefore, the value of the continuum impact pressure cannot be measured in the tunnel. Rather, an extrapolation technique, which has been employed in most of the previous studies by other investigators (Ref. 2), was utilized in the present study. This procedure involves a certain amount of arbitrariness which may lead to errors. In order to minimize these errors, a theoretical determination was made of the impact-pressure variation from the continuum flow through the so-called "incipient merged layer" regime, which then served to guide the extrapolation process. It should be noted that the available theory will predict the initial decrease in impact pressure as the rarefied-flow regime is entered, but is not capable of predicting the pressure rise which follows. Also, it is pointed out that (Ref. 3) provides an excellent description of the various low-density flow regimes which are mentioned here.

The present experimental results clearly indicate a Mach number dependence which is typically illustrated in Fig. 1. It may be seen that, as the probe becomes smaller, which is indicated by a decreasing probe Reynolds number, $R_{e\infty}$, the impact pressure first decreases and then rises sharply. Also, at a given Reynolds number, it is seen that the measured pressure, P_{o_m}, which is normalized with the continuum pressure, P_{o_i}, is greater at the higher Mach numbers. Also shown in Fig. 1 are the low Mach number results of Sherman (4) and Matthews (5) which agree with the Mach number trend of the present data.

It was found that the parameter, $M\infty / (R_{e\infty})^{1/2}$, satisfactorily correlated the test data through the test Reynolds number range of about 50 to 350. This is illustrated in Fig. 2 where it may be seen that the data points collapse to a single curve. This means that, for any blunt body having a similarly shaped nose, the impact pressure on the body nose should be the same as presented here when the value of $M\infty /(R_{e\infty})^{1/2}$ is the same; therefore, the governing parameter has been determined for this particular Reynolds number range. It was found that the Knudsen number alone would not properly correlate the data. It was also found that, for the flat-ended probes, the ratio of the probe diameter to the pressure orifice diameter had essentially a negligible effect on the impact pressure. However, for a hemisphere-tipped probe, the impact-pressure rise occurred at appreciably greater probe Reynolds number than for the flat-ended probes.

It is suggested that the impact-pressure behavior may be explained as follows: in hypersonic continuum flow, a strong bow shock wave stands in front of the blunt body across which the flow decelerates to a Mach number of about 0.4 and the pressure increases greatly. The dynamic pressure behind the shock amounts to about 10 per cent of the total pressure there. Behind the shock and at the stagnation point on the body, the flow is brought to rest isentropically and the dynamic pressure is recovered as static pressure. For this case, there is a very thin boundary layer over the nose. As the flow becomes rarefied, the boundary layer on the body thickens, viscous losses occur, and recovery of the dynamic pressure behind the shock is no longer isentropic. With further rarefaction, the shock wave moves farther away from the body and the shock strength weakens. Eventually, the rarefaction effects on the shock predominate over the viscous effects on the body, and the impact pressure increases; with sufficient rarefaction, the molecules begin to make direct impact on the body, and the free molecule flow regime is being approached.

The results of the present study will have a direct application to experimental low-density hypersonic studies in the laboratory. Also, since results may be generalized to the blunt-body flow conditions, the results may

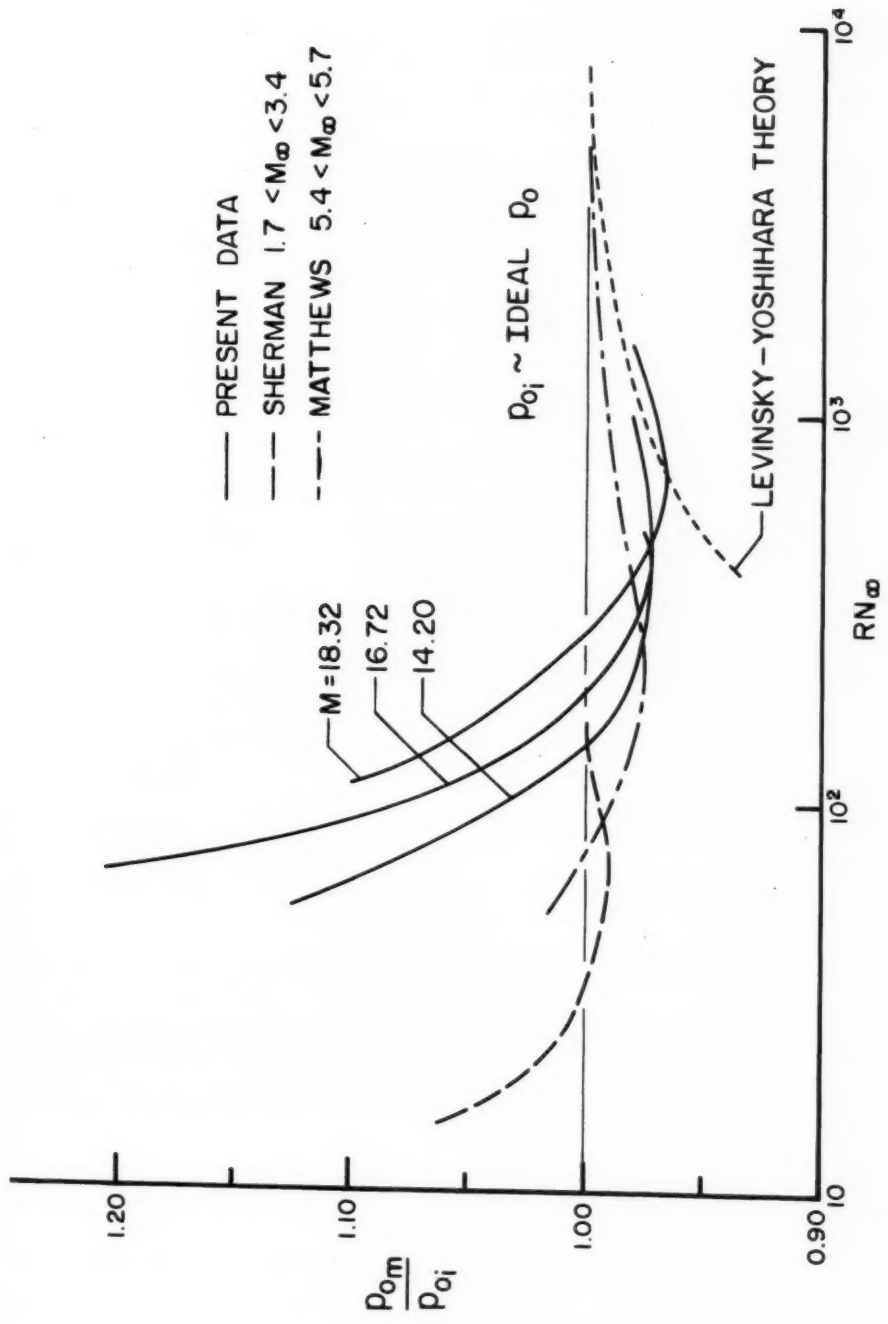

Fig.1. TYPICAL MACH NUMBER EFFECTS ON BLUNT-BODY IMPACT PRESSURE

also find application in the blunt-body gas dynamic situation in the range of $M_\infty/(R_{e\infty})^{1/2}$ covered in the present investigation. ★

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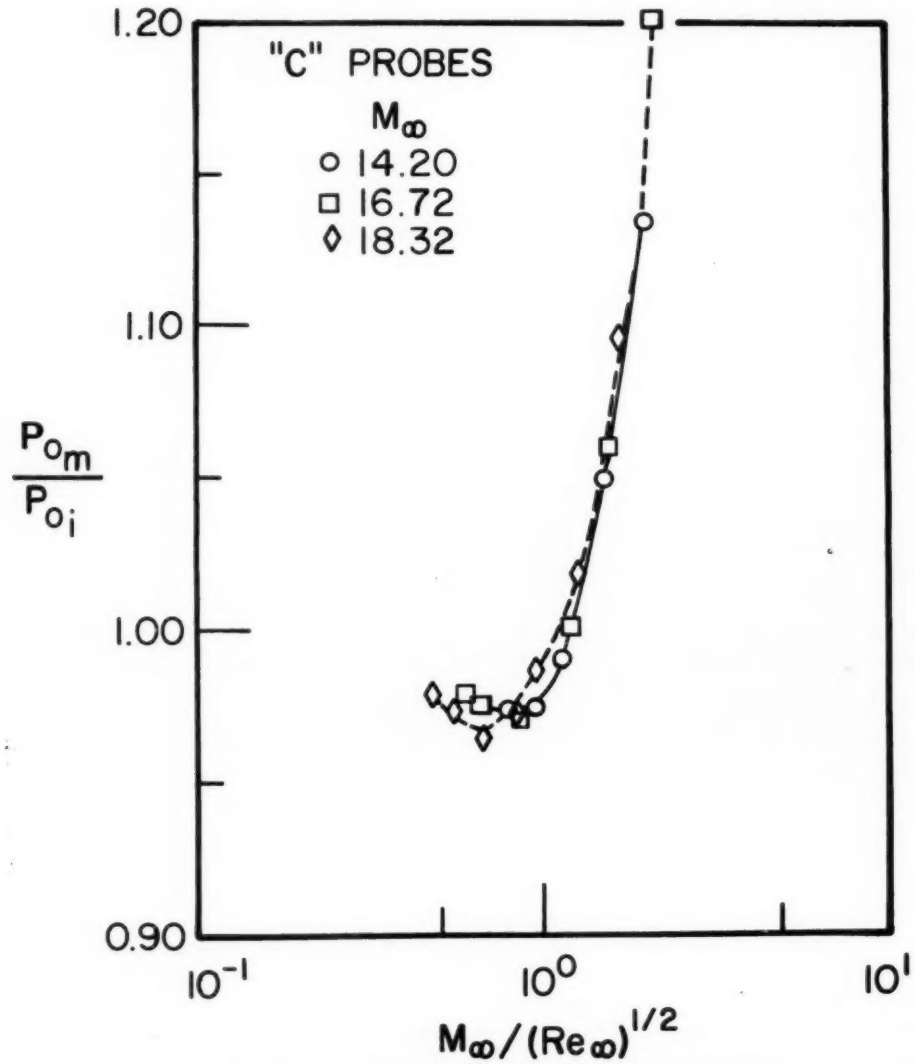

Fig. 2. TYPICAL EFFECTIVENESS OF CORRELATING PARAMETER

PROFILES

Captain Vern G. Smalley is a physicist with the Lunar-Planetary Research Branch, Space Physics Laboratory, AFCRL. From April 1963 to the present, he has been concerned with the nature of the lunar-surface layer, the lunar environment, and planetary environments. The article, "Shrinking Moon?" in this issue of the Review describes some of his work. Captain Smalley has a B.S. in Physics from Montana State College (1959), and an M.S. in Physics from the University of Michigan (1963). From 1959 to 1961, he was a Nuclear Research Officer with the Flight Control Laboratory, ASD, Wright-Patterson AFB, Ohio. He has several publications to his credit.

1st Lt Graydon A. Elliott, an ARL scientist, is co-author of the article, "Impact-Pressure Behavior in Rarefied Hypersonic Flow," which appears in this issue of the Review. At ARL's Hypersonic Research Laboratory, he works primarily in the area of hypersonic aerodynamics. Presently, he is engaged in a study of Reynolds number and Mach number effects on impact-pressure probes used in hypersonic wind tunnels. He is also investigating the design criteria for a supersonic air-to-air ejector for wind-tunnel application. Lt Elliott has a B.S. in Aeronautical Engineering from Virginia Polytechnic Institute (1960), and an M.S. in Aeronautical Engineering from Southern Methodist University (1964). He came to ARL just last year.

Mr. Fred L. Daum, an ARL scientist with the Hypersonic Research Laboratory, is co-author of the article, "Impact-Pressure Behavior in Rarefied Hypersonic Flow," which appears in this issue of the Review. He recently completed and reported on an investigation of air condensation on the air flow in a hypersonic wind tunnel. Presently, in the interest of exploiting the results of the air-condensation program, he has under way a study of the problems of attaining uniform parallel flow at Mach 20. Mr. Daum has a B.S. in Aeronautical Engineering from the University of Cincinnati. He spent several years with NACA at Langley Field, and with AMC at Wright Field before joining ARL in 1951. He has a number of publications to his credit.

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